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A Thermal Control System for an Isostatic Press

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A Thermal Control System for an Isostatic Press

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1 Executive Summary

This paper proposes a concept of operation for an isostatic pressing capability using a proposed thermally controlled system developed using system engineering methodology. The concept utilizes a computer controlled fluid based heat exchange system capable of heating or cooling a pressure vessel in which high explosive (HE) is isostatically pressed. A press operator controls the system through a computer interface.

The methodology employed to create the concept of operation was developed by first identifying and describing a mission need to revitalize a capability used research and development of HE. The context of the mission is captured with a discussion of the relevant stakeholders and their expectations regarding the identified need. A system is constructed to address the stated needs with a context diagram employed to define and bound the system under study. Further described are constraints and performance drivers to the system under consideration with likely operational scenarios analyzed to ensure the proposed system processes them correctly. A review of possible implementation concepts is completed with rationale for their selection and discussion of their attributes. The technical approaches are assessed with a preferred approach recommended. Functional and physical architecture of the system is shown in the context of existing legacy architecture. The expectations of the stakeholders are cross-walked with a developed list of system requirements. Likely business and organizational impacts are stated as well as potential risks to the realization of the concept.

2 Mission Description

2.1 Mission Context

As a national security laboratory one of Lawrence Livermore National Laboratory's (LLNL) primary missions is to ensure the safe, secure and reliable operation of current nuclear stockpile systems for the United States of America. Within LLNL, the Weapons and Complex Directorate (WCI) directorate is responsible for fulfilling the goals and requirements of the nuclear Stockpile Stewardship and Management Program (SSMP) as instituted by the Department of Energy's, National Nuclear Security Agency. A key component of the weapon system is the HE assembly as its performance drives subsequent nuclear processes. It follows the study, development and testing of energetic materials used in weapons system is of particular importance.

One such capability WCI has that provides for the development and testing of energetic materials used in weapon systems is a High Explosive (HE) pressing facility complex located at LLNL's remote experimental test site, S-300. This remote site was established in 1955 to conduct non-nuclear explosive testing in support of LLNL's national security mission.

Currently the pressing capability is nonoperational as the TCS function of the press was found to be inadequate and removed several years ago. The capability has sat dormant awaiting funding and a plan or design on how to make operational. The ability to press HE in desired shapes with required material properties is an important element of the Weapons Program at LLNL at it studies and evaluates the performance of weapons systems.

When operational the facility under consideration will be able to produce HE pressings larger then currently can be made at LLNL. This has been stated as a need by several missions at LLNL, as it will allow subsequent assemblies to be made with fewer parts and more nearly represent actual or potential use of articles under test. When functional the pressing system will produce pressed parts that meet technical performance criteria, which consist of parts meeting dimensional accuracy, achieving specified densities, low porosity and without cracks or internal flaws. These characteristics are important as they enable higher quality weapons components to be fabricated which result in less uncertainty in the performance of the weapons systems. A representation of the thermally controlled isostatic pressing capability is shown in Figure 1.

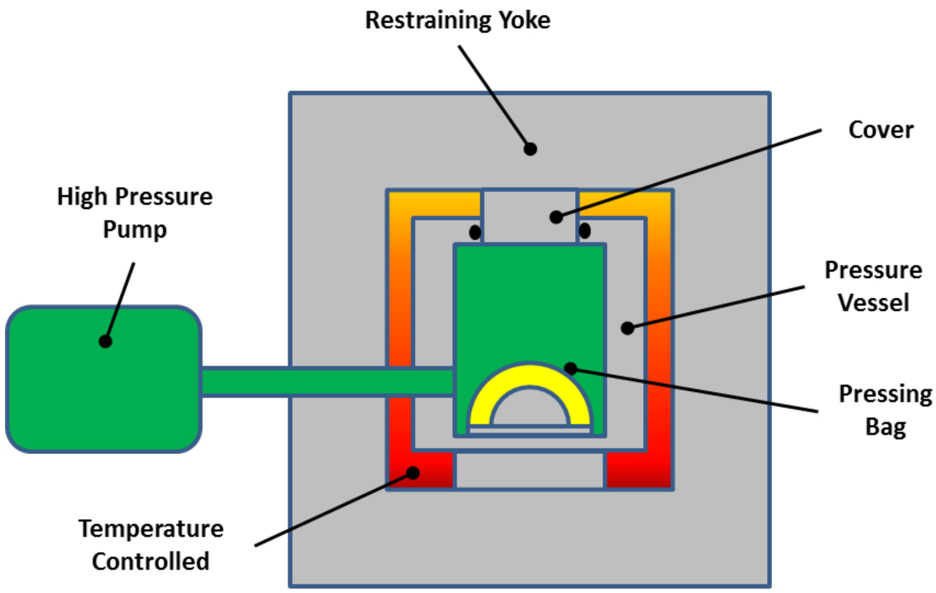

Figure 1: Temperature Controlled Isostatic Press

2.2 Stakeholders

A review of the all the possible stakeholders was considered, however only those with the most interest and possible influence on the implementation of the TCS are presented. Other stakeholders (i.e. newspaper/media, public at large, activists, etc.) who may have an interest but not likely not to influence the resulting system are recognized but not included in this evaluation.

The primary stakeholders from the mission or program side are noted as follows:

- The previously stated performance characteristics are of primary concern to WCI's physicists as they directly affect the performance of weapons systems under study.
- These requirements are flowed down to energetic materials chemists who develop materials capable of achieving the desired energetic explosive properties.
- Engineers in turn are responsible for ensuring the HE part is produced with the specified shape at required accuracies.

On the operations side of the pressing capability the stakeholders are:

- The press operator is the individual who performs the operations that actually produce the HE part.
- The facility manager makes available a facility with necessary infrastructure to allow pressing operations to occur.
- Maintenance personnel carry out both planned maintenance and corrective maintenance tasks when needed on the pressing equipment.

Of the stakeholders previously mentioned the operations personnel are considered as active as they have direct interaction with press and the proposed TCS. The program personnel prescribe the performance characteristics but do not directly interact with the system. The active stakeholders with their expectations are noted in Table 1.

Role	Description	Expectations
Press Operator	The Press Operator is responsible for all operations of the press. To include activities in preparation of pressing operations, the actual pressing operation and post pressing activities.	The TCS should be easy to use and reliable. The TCS should be able to control locally and remotely. The ability to monitor and record processing temperatures is desired.
Facility Manager	The Facility Manager is responsible for providing a facility in which pressing operations can be carried out.	The TCS should be safe to operate and compatible with existing press and utility systems of the facility. Cost of operation and maintenance should not be prohibitive.
Maintenance Personnel	These personnel are responsible for maintaining the facility system to include the TCS and pressing system.	The TCS should be designed to allow ease of maintenance with use of common components and readily obtainable supplies.

Table 1: Active Stakeholder in HE Pressing Operations

As noted previously there are numerous passive stakeholders associated with the pressing capability, a few key stakeholders are discussed in the following text.

The Environment Safety and Health (ES&H) team is comprised of safety experts in various fields; Industrial Safety, Industrial Hygiene, Explosive Safety, Health Physics and Environmental. They are primarily responsible for reviewing and approving operations and activities within the pressing facility as they are expecting the proposed TCS to be first and foremost safe. Another stakeholder is the S-300 Manager, he is responsible for all operation at S-300, the Site Manager needs to be assured the pressing capability can be operated safely and be compliant with applicable regulatory requirements. By extension the regulatory agencies want see the operations of the pressing capability are complaint.

Another passive stakeholder is LLNL's oversight agency, NNSA. The Livermore Field Office of NNSA confirms development and subsequent operations of the pressing capability are aligned with overall NNSA program missions as well concur on the safe and environmental sound operation of an upgraded capability. These same expectation are held by NNSA headquarter office located In Washington D.C. An additional group of passive stakeholders are the local neighbors of S-300. They are interested in ensuring any test and development capabilities at S-300 will not impose a hindrance or obstacle in their normal course of activities.

Both WCI program management as well as LLNL institutional organizations are considered passive stakeholder. WCI program management will likely be the funding source for the execution of this proposed project, they will expect the project be carried out safely, meet performance requirements, be completed to an estimated schedule and within budget. The institutional stakeholders are organization such as the engineering department, procurement office, shipping/ receiving, legal counsel and the like. Each of these organizations has the expectation the project and subsequent operations will follow their policies and procedures. The passive stakeholders are described further in Table 2.

Role	Description	Expectation
Physicist	Responsible for defining characteristics of the explosives used in weapons systems	The press should be able to produce parts to specifications.
Chemist	Develops the formulation and specifies HE pressing process parameters.	The press needs to maintain the prescribed temperatures and pressures.
Engineer	Defines the shape and dimensional accuracy required for the pressed part and associated tooling.	Existing tools and supplies should be usable with the proposed operations.
ES&H Team	This team reviews the planned implementation and operation of the TCS system for the press.	Expects the TCS to operate safely and not impose a hazard to employees or the environment.
Site 300 Manager	Responsible for all operations at the site, to include the installation and operation of the press.	Expects the press to meet program requirements and meet LLNL safety and operation requirements.
State and Federal Regulator	Sets policy for operations which involve public safety and environment concerns. Perform audits and site inspection to ensure compliance.	Assumes their codes and regulation to be followed. Will be able to visit site to ensure so.
NNSA Livermore Field Office and Washington DC Headquarter	Provides oversight and confirm LLNL activities and operations are aligned with NNSA mission and goals.	Will require sufficient reporting of project progress as well as subsequent operations.
Local Neighbors	Neighbors include both those having land immediately adjacent to S-300 as well as those that live in a community within 20 miles	Wants operations at S-300 to not harm the environment or be detriment to their community.
Program Management	Responsible for directing and managing LLNL efforts and activities that address NNSA programs and mission.	Expects the pressing capability to be revitalized in a manner that meets performance goals, stays within budget and maintains schedule.
LLNL Institutions	These include Engineering, Procurement, Office of Legal Counsel, Assurances, etc.	Expect the system will be implemented in manner that meets policy.

Table 2: Passive Stakeholders in the HE Pressing Operations

2.3 Sacred Expectations and Context Diagram

After review, the expectations stated by the both the active and passive stakeholders have been distilled down to the essential non-functional requirements or scared expectations of the thermal control system (TCS) as shown in Table 3. These are considered the critical attributes the system must have to operate successfully.

Sacred Expectations
Operate reliably
Ease of use
Ease of maintenance
Be safe to operate
Integrate in existing facility

Table 3: TCS Non-Functional Requirements

Given the expectations of the various stakeholders and with the knowledge of the existing infrastructure and press hardware a context diagram has been developed (Figure 2) that bounds the system and shows how the active stakeholders will interact with the system. Also shown in the diagram are envisioned major subsystems of the TCS. These will be described further in Section 5 (Operational Scenarios) and Section 6 (System Implementation) of this document.

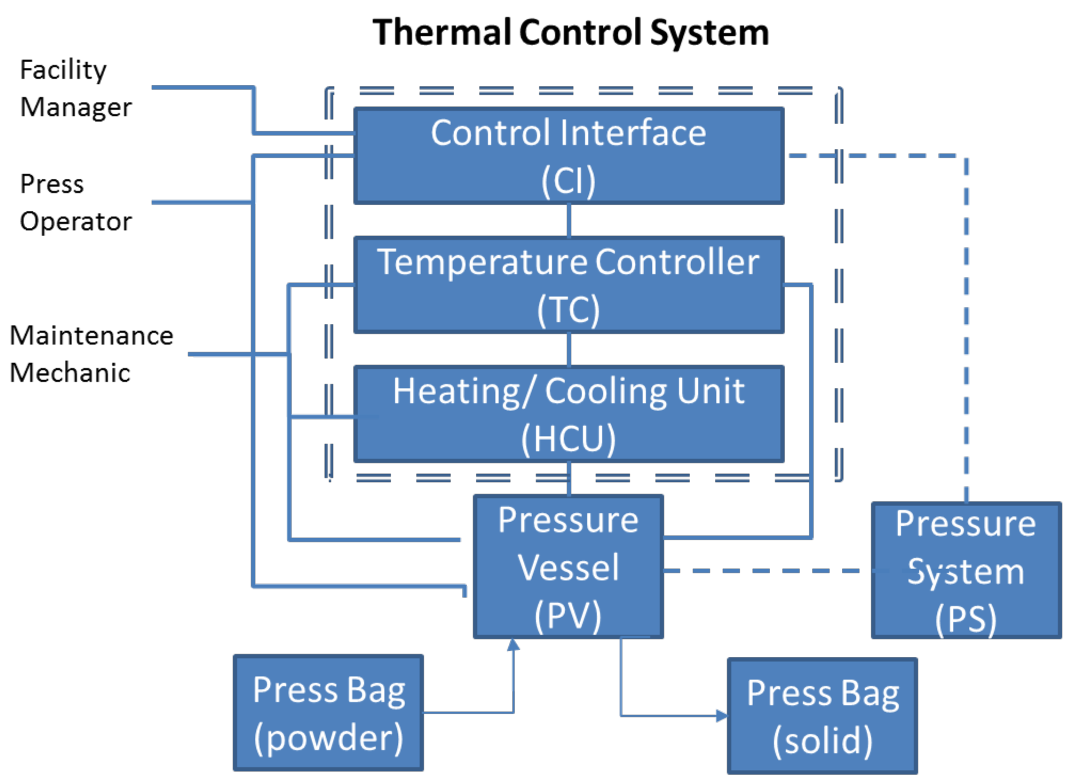

Figure 2: Context Diagram of a Thermal Control System for an Isostatic Press

3 System Operational Context and Reference Operational Architecture

The goal of this system engineering proposal is to show a system can be designed that addresses the failed temperature control capability of the existing pressing vessel while meeting the expectation of the stakeholders. Key to this is a thorough understanding of the construct and operation of the existing pressing capability, supporting facility and infrastructure.

3.1 Capability of Existing Facility Systems

The facility has the capacity when fully operational of producing large cylindrical HE parts. The proposal is to retrofit the existing facility system to develop its full capability by providing a TCS for the high pressure isostatic press. The high pressure system, capable of reaching 30,000 psig, has not been used in several years and is in need of maintenance. This is being addressed as part of a larger effort that is considering the revitalization of the entire facility complex. As noted previously the focus of this study is the employment of system engineering methodology in design and implementation of a TCS for the press. The new system will be designed and implemented to be compatible with all technical, operational and safety requirements. As noted equally important, the proposed system needs to integrate with existing press system and facility infrastructure elements (power, water, etc.). A photo of the existing press with restraining yoke pulled away from the pressure vessel is shown in Figure 3.

Figure 3: Photograph of existing pressure vessel and restraining yoke (Note the diamond flooring swings up and out of the way to allow the yoke to travel over the vessel for high pressure operations).

As noted the TCS will reside in an existing facility and will be required to fit-in and interface within existing rooms, space and provide infrastructure utilities. Photographs are provided to the further describe the facility, Figure 4 and 5.

Figure 4

Figure 5: Control Room (left); Back of Pressure Vessel (right)

3.2 HE Pressing Process

The process to create an HE pressing of the desired size, density and porosity starts with the delivery of preheated HE powder in an evacuated bag. Within the bag is a mandrel to which the HE powder will conform to shape when subject to high pressures and temperature. The press is preheated to the desired temperature prior to delivery of the bagged mandrel. Once delivered to the press on a cart, the bag will be picked up with an overhead crane and trolleyed over the press and lowered into the inner bore of the press cylinder. A local control panel is accessed to close the lid on the press cylinder and move the restraining yoke over the cylinder. Once the lid is secured personnel move to the remote operations room for subsequent steps.

These steps include the securing of the room to ensure all personnel are removed and door interlocks set. Additional security steps include the activation of a remote video system to document activity within the pressing room. Finally the press operator interfaces with a computer controlled pressure system is used to select a predetermined time dependent pressure profile. The computer control pressure system opens valves to purge the system of entrapped air before starting the pressure cycle. This will happen in conjunction with the proposed TCS which will maintain the temperature of pressure vessel at the prescribed set-point. Temperature is recorded at multiple locations in the system to include the fluid within the pressure vessel itself. As part of safety requirements, a redundant temperature measurement and shutdown system will be incorporated. This system feature will shut down the TCS system as well as pressure system if the temperature exceeds the maximum allowable temperature of the HE being pressed.

4 System Drivers and Constraints

The primary performance of the TCS as the name implies is the control of the temperature pressure vessel and pressing fluid (glycerin) around the HE bag. The HE chemist has provided specifications for the press which consist of a maximum/ minimum operating temperature, temperature stability, maximum allowable temperature and rates at which the temperature is to be raised or lowered. These are shown in Table 4.

Temperature Parameter	***Description***	***Temperature/ Time****
Maximum Operating	The maximum processing set-point temperature at which the glycerin in the pressing vessel shall be required to be maintained.	135 C
Minimum Operating	The minimum processing set-point temperature at which the glycerin in the pressing vessel shall be required to be maintained.	40 C
Uniformity	The temperature of the glycerin within the pressing vessel shall be uniform throughout the liquid volume and not vary by more than specified.	+/- 3 C
Maximum Allowable	The temperature of the pressing vessel shall not exceed the amount specified.	150 C
Starting Temp. Time Allowance	Starting from an ambient temperature of 20 C the minimum or maximum operating temperature shall be achieved within the specified time period.	24 hours
Operating Temp. Time Allowance	The ability to ramp up to and down between to two glycerin set-point temperatures over a specified period shall be provided	24 hours

* These parameters are notional and do not represent actual performance values.

Table 4: Thermal Control System Operational Temperature Parameters

As required, the TCS shall operate safely and meet all imposed safety requirements. In addition to standard industrial safety considerations associated with high pressure systems, components at elevated temperature and other hazards introduced by the selected TCS, the TCS shall meet safety requirements associated with operating in a hazardous HE environment.

The requirements associated with industrial and explosive hazards will be outlined by the facility ES&H team. The standard industrial hazards will be mitigated following LLNL ES&H manual which meets contractual requirements between LLNL and the NNSA and follow national safety standards imposed by OSHA, NEC, NFPA and the like.

The explosive requirements are specified in a Department of Energy (DOE) Explosive Safety Standard (DOE-STD-1212). There are two primary drivers in the standard that the TCS has to meet. The first is any system which relies on electrical energy or is capable of reaching over the maximum operating temperature shall have a redundant temperature measurement and shut-down system. The second is any component within the pressing vessel bay shall be compatible with a hazardous location specified as a Class II Division 2. This is consistent with the room location having the potential to be exposed to explosive dust (Class 2) in an off normal event (Division 2).

The TCS must integrate with sub-systems of the existing press and facility infrastructure. These systems include a glycerin based high pressure system which generate up to 30,000 psi. The glycerin is introduced into the pressure vessel in which the HE bag resides. The TCS must be compatible with the operation of this high pressure system which consists of the pressure vessel, mechanical yoke and ancillary systems.

Additionally the TCS should be compatible with existing facility utility systems which include electrical power, compressed air, vacuum, HVAC, lighting and water systems. Each of these systems is used within the facility but maybe utilized as needed by the TCS as long as the demands of the TCS are consistent with what can be delivered by identified utility.

5 Operational Scenarios

In order to confirm the proper development of the context diagram by showing it meets the requirements imposed by legacy architecture as well system drivers several operational scenarios were considered. Sequence diagrams were used as means to ensure the functionality of the selected operation is carried out by the proposed subsystems.

<u>Evaluated Operational Scenarios</u>

1. Pre-heating pressure vessel prior to loading of HE bag:
   - The first scenario considered preheats the pressure vessel in preparation for a HE bag to be loaded. The facility, TCS, associated systems and infrastructure are initially at ambient temperature of 20C (Figure 6).
2. Maintain elevated temperature during pressing operation:
   - The second scenario considered maintains an elevated temperature of HE in the pressure vessel during high pressure operations. The TCS is starting at an elevated temperature near the selected set-point temperature (Figure 7).
3. Reduce temperature in press to lower set-point temperature:
   - The third scenario reduces the temperature of pressure vessel and HE bag from an elevated temperature to an intermediate temperature above ambient temperature and hold for a predetermined time (Figure 8).
4. Maintenance operation:
   - The fourth scenario is a maintenance operation, in which the maintenance crew has to perform maintenance on the heating/ cooling unit (Figure 9).
5. Off Normal, temperature in excess of allowable:
   - The fifth scenario considers an off-normal event in which the temperature of the pressure vessel approaches the maximum allow temperature (Figure 10).

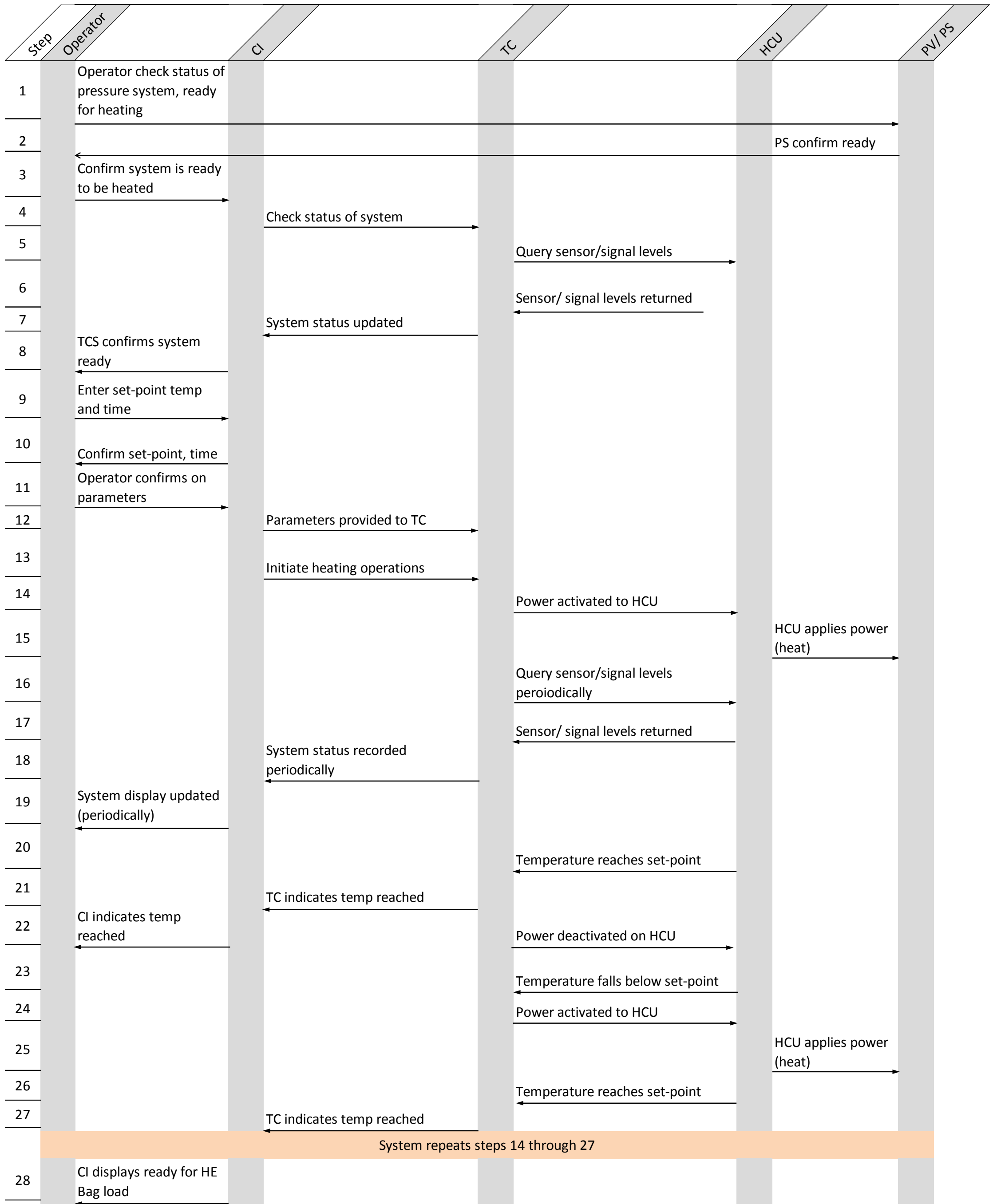

Figure 6: Sequence Diagram – Pre-Heat Pressure Vessel

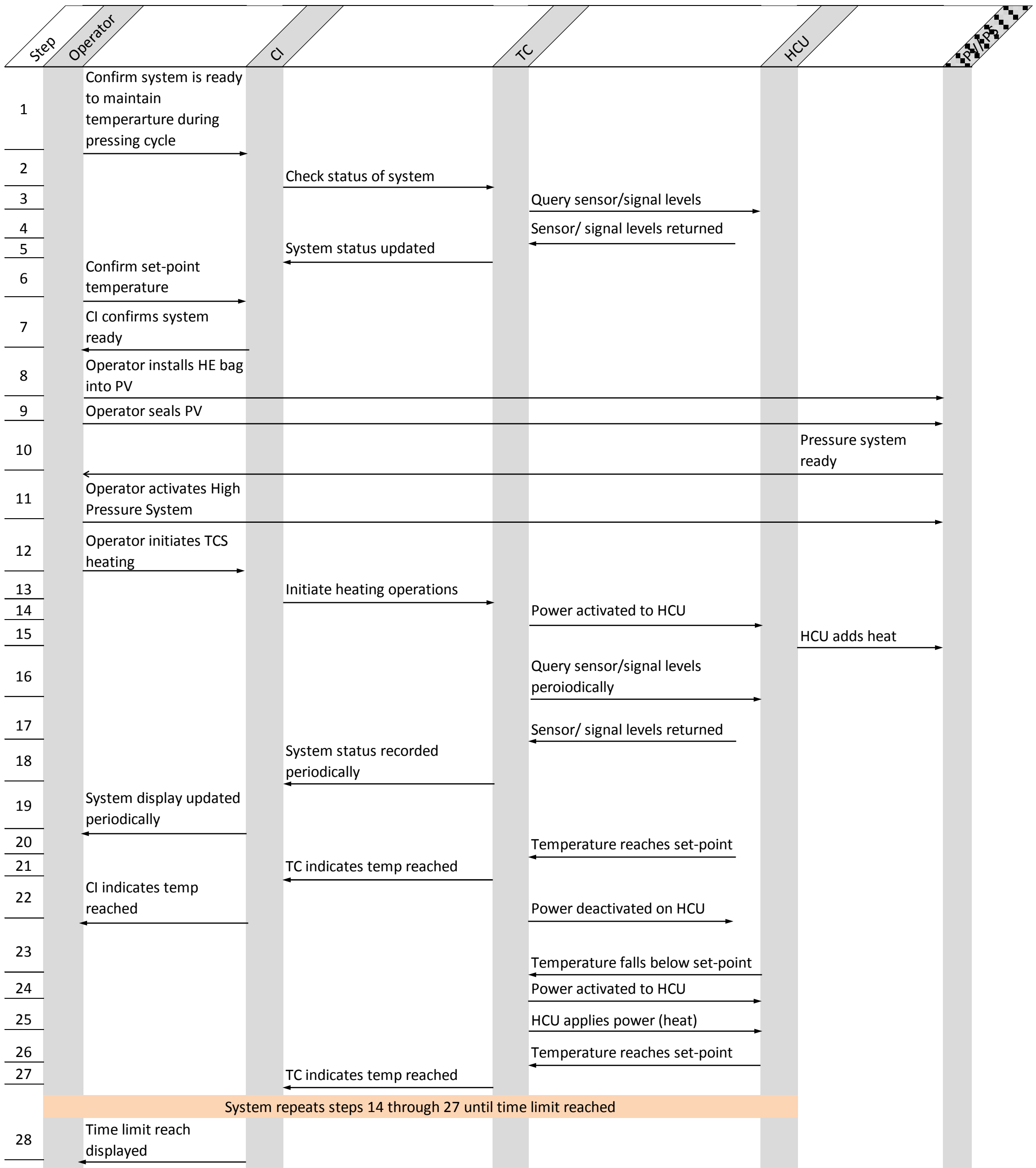

Figure 7: Scenario 2 - Maintain Set-Point Temperature during Pressing Operations

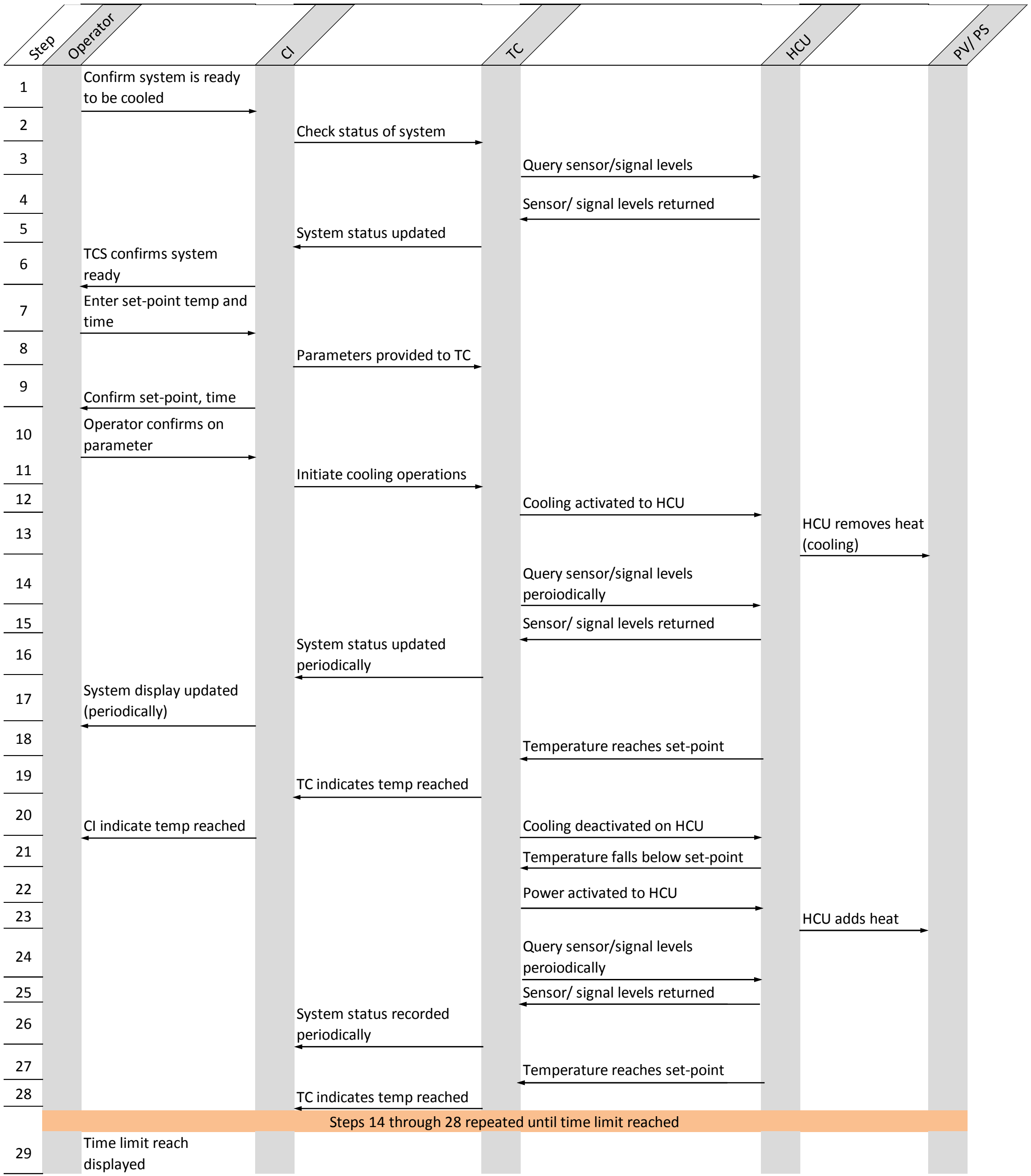

Figure 8: Scenario 3 – Set-Point Temperature Reduce to Intermediate Temperature

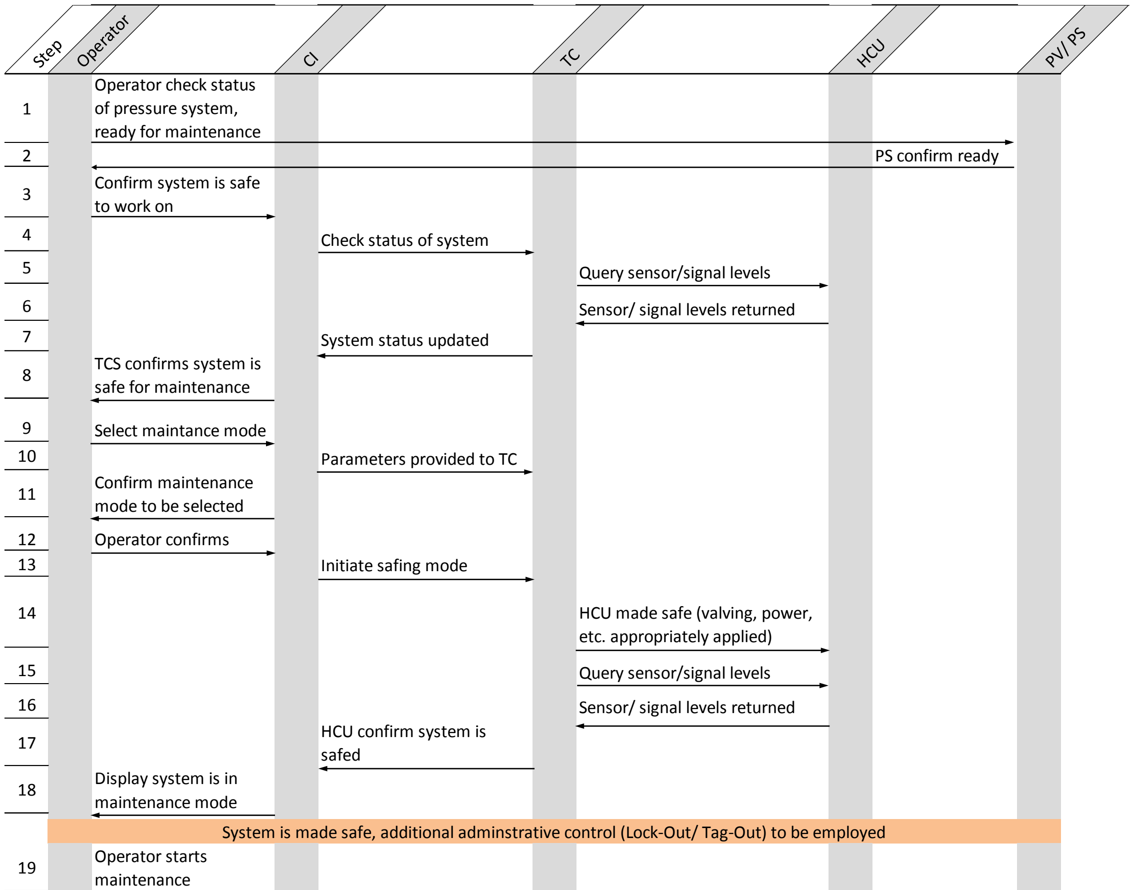

Figure 9: Scenario 4 – Maintenance Operation on TCS

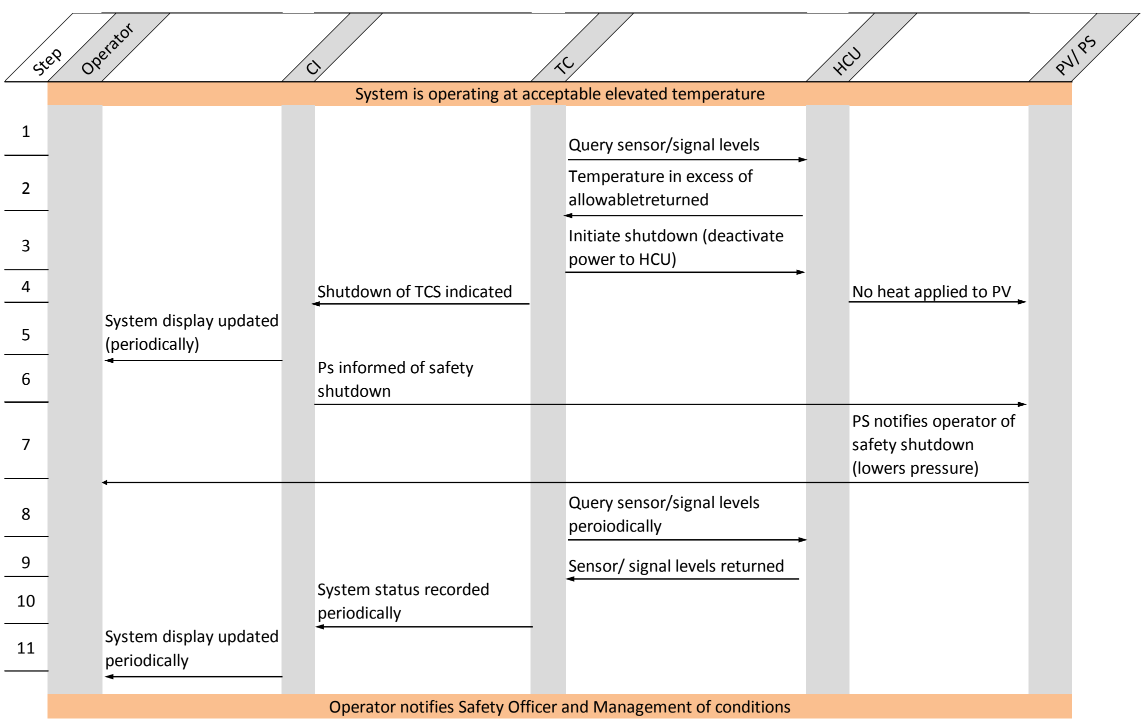

Figure 10: Scenario 5 – Off-Normal Condition, Excess Temperature

6 Implementation Concepts Selected and Rationale

Preliminary scoping calculations have been completed that bound the heat or power required to elevate the pressure vessel from ambient condition to maximum temperature in the time prescribed. A power or heat input of 11 kW has been calculated that will meet the time and temperature requirements. Several technical approached are considered as a means to meet the expectations and requirements of the TCS.

For each approach, the portion of the system that interfaces with the active stakeholders (the Controller Interface) is thought to be the same. The CI would be a touch screen or keyboard/monitor interface that allows the operator to input commands and monitor the system status and performance. Both specific levels will be displayed as well a time history plot of selected parameters. Specified heating profiles can be viewed and compared against actuals. In addition data log files will be generated that record the time history of selected parameters. These will be available for download and offline analysis.

6.1 Water Based System

In this system water flowing through a closed loop will act as both the heating and cooling medium flowing around outer surface of the pressure vessel. The temperature of the water is controlled by a heating/ chiller unit. The units are commercially available as an integral part of the HCU with associated piping likely rated as an ASME pressure vessel given the temperature requirements. Control valves and piping will be used to direct the flow of water through the heating/ chiller unit and around the pressure vessel.

Temperature sensors will be placed throughout the system to monitor the performance of the system and provide input to the control logic. A programmable logic controller (PLC) will control the sequence of valving, pump speeds, the rate of heat added or removed by the water. The PLC receives commands from the CI as directed by the system operator.

All component of this system are commercially available items with no technical development required. Control software will have to be written for the specific system designed. A thorough acceptance testing protocol developed and executed will be required to ensure the system responds as needed for the defined use cases as well as handles off-normal events in manner that renders the system safe.

6.2 Non Water Fluid Based System

As in the previous concept a closed looped system is envisioned to provide temperature control. However the fluid selected should have boiling point lower than the maximum allowable set point temperature. This allows for a circulating fluid system to be designed which does not have to be a rated ASME pressure system. Candidate materials for fluid are glycerin which has a boiling point of 290C, well above the set-point temperature. However it is very viscous at ambient temperatures (1,412 centipoise) making it difficult to pump and flow the system. A small amount of water maybe added (~5%) which will reduce the viscosity (~520 centipoise) while only slightly reducing the boiling point. This will result in a similar viscosity as SAE 30W motor oil, thus allowing the fluid to be pumped at lower pressures.

All other aspects of the system with regard to controlling logic, temperature pressure monitoring and control logic are similar to that described previously.

6.3 Thermo-Electric Based System

This system concept utilizes commercially available thermoelectric devices which use the Peltier effect to convert electricity into a temperature difference across the device. The system would incorporate a bank of devices attached around the perimeter of the pressure vessel to both heat and cool the HE bag. A search resulted in finding commercially available devices capable relatively high heat flux, up to 200 W per device.

However there are technical limitations and constraints to this approach. One has to do with a thermodynamic limitation of the Peltier effect for the selected devices which introduces a maximum temperature difference across the device of approximately 70C. Therefore the devices will have to be applied in series across the heat flow boundary, with one device output coupled to the device input another and so.

Another constrain is a recognition of the interrelationship of powered transferred to allowable temperature difference. Of note, the power transferred across these devices is inversely proportional to the temperature difference across the device. As an example one device investigated was capable of transferring 220 W at 0C, but also able hold off a temperature difference of 60C at 0W transferred. Therefore an intermediate point will have to be selected that allow a reasonable temperature difference to be achieved as well as transfer heat. This will lead to an increase number of device stacked in series. And finally these devices are very inefficient as cooling devices with three to four times as much heat lost as is transferred across the device. This excess heat will have to be dealt with in the form of an exterior heat sink and convective air cooling.

As this approach is electrical based addition controls and design requirements are imposed by the DOE explosive safety standards. The first being electrical components need to be rated for use in a hazardous environment previously noted as Class II Division 2. It is not clear these are commercially available at this time, though they could be qualified as an undefined cost. Another approach is to place components in a potting compound to isolate the device from the environment or build an enclosure subject to positive pressure to keep the facility atmospheric environment away from the electrical devices in questions. Any of these techniques will add cost and complexity the overall design.

The control of this system is similar to that described previously and will utilize PLC's with input from temperature sensors to control the power supplied to the banks TEC devices. As this approach is the least efficient of those being considered, it will require more power than other approaches.

6.4 Resistive Heating/ Fluid Cooled Based System

The approach is a hybrid of a previous presented concept with a fluid based system used to provide cooling of the pressure vessel. The difference on this approach is to use standard resistive heating element to apply to apply heat and maintain temperature.

The concept would attach a series of heating elements to the exterior surface of the vessel with the cooling system attached the outer surface of the heating elements. For heating operation the cooling system would either be turned off or run at a low level to help dissipate the excess heat of the heating elements. But not run at a high enough cooling capacity to hinder the performance of the heaters. Commercially available heaters used to heat process chemicals in drums are considered a viable approach. The cooling would be similar to that described for either of the fluid based systems. The difference thought it would not have to operate at an elevated temperature for extended periods. Because this incorporates electrical based heating elements the system will require additional controls and design features needed to address HE safety requirements associated with operating in a hazardous environment.

In order to make a down select to the preferred technical approach a Pugh diagram was generated to evaluate the options (Table 4). The results show the fluid based systems ranked more favorable compared to the system that utilized electrical energy to either heat or cool the press. This due to additional constraints imposed by the explosive safety standards for heating system components that electrical based. The non-water based system had a slight edge over the water based system, primarily based on the fact the design of the piping and heat exchange system would not have to be rated as a pressure vessel under the ASME boiler and pressure vessel code. However in the development of the actual design both approaches should be evaluated using system engineering techniques as subsystems within the design become further defined.

Criteria	Thermal Control System Options: Water Based	Non-Water Based	Thermo-Electric	Resistive Heating
Operate reliably	0	0	-1	0
Ease of use	0	0	0	0
Be safe to operate	+1	+1	0	0
Ease of maintenance	0	0	-1	+1
Integrate into existing facility	0	0	0	-1
Complexity of system	0	+1	-1	-1
Additional controls required for HE safety	+1	+1	-1	-1
Score Total	+2	+3	-4	-2

Table 4: Pugh diagram of TCS options

7 Proposed System Operational Architecture

As the TCS is being integrated into an existing press the proposed thermal system should minimize any changes to the pressing system. In order to accomplish this, the existing system design documents and specification will need to be reviewed and understood to ensure new functions or operational are compatible with the legacy equipment. Areas of particular interest are of course the pressure vessel itself and how it is integrated in the rest of the press system.

7.1 Physical Architecture

Of particular note are the constraints imposed by the physical architecture of the mechanical equipment. The portion of the TCS that directly heats or cools the pressure vessel will have to fit within the available space between outer surface of the vessel and the inner surface of blue restraining yoke. A preliminary review of drawing indicates there is approximately 12cm of clearance. The pressure vessel with the restraining yoke pulled away from the vessel is shown in Figure 11. This is the configuration of the equipment for maintenance on the vessel as well as the loading or unloading of the HE pressing bag.

Figure 11: Existing vessel with restraining yoke pulled away

One area of the existing architecture which is open to modification and modernization is the local interface to control the press during operations which do not involve HE. The existing pedestal (Figure 12) has been shown to be hard to read and unreliable. A local interface device would incorporate both controls for the mechanical operation of the press as well thermal system.

Figure 12: Existing local control pendant

7.2 Functional Architecture

A functional architectural diagram was developed that considers the primary functional elements thermal control system, Figure 13. Of note is the inter-relationship of the identified functions of the system as they address expectations the active stakeholders. A few examples will be discussed.

A natural expectation voiced by all the active stakeholders was the system shall be capable of operating safely. This is especially true with regard to HE operations; the function of a safety shutdown process is included which will remove all power to the pressure vessel in the event temperature approaches the maximum allowable temperature of 150C.

Another characteristic voiced by both the operator and maintenance crew is the ability to control and monitor the conditions of the thermal system both locally in the room the pressure vessel is located as well as the remote control room. Additionally the ability to both display current temperature readings as well history of temperature is provided in the display as recorded for off-line analysis.

And finally as noted the thermal system shall integrate into the existing pressure system, this characteristic is shown through the functionality provided interfacing with the pressure system status. What exactly that is still to be determined, whether it include pressure levels or just indicate it is active.

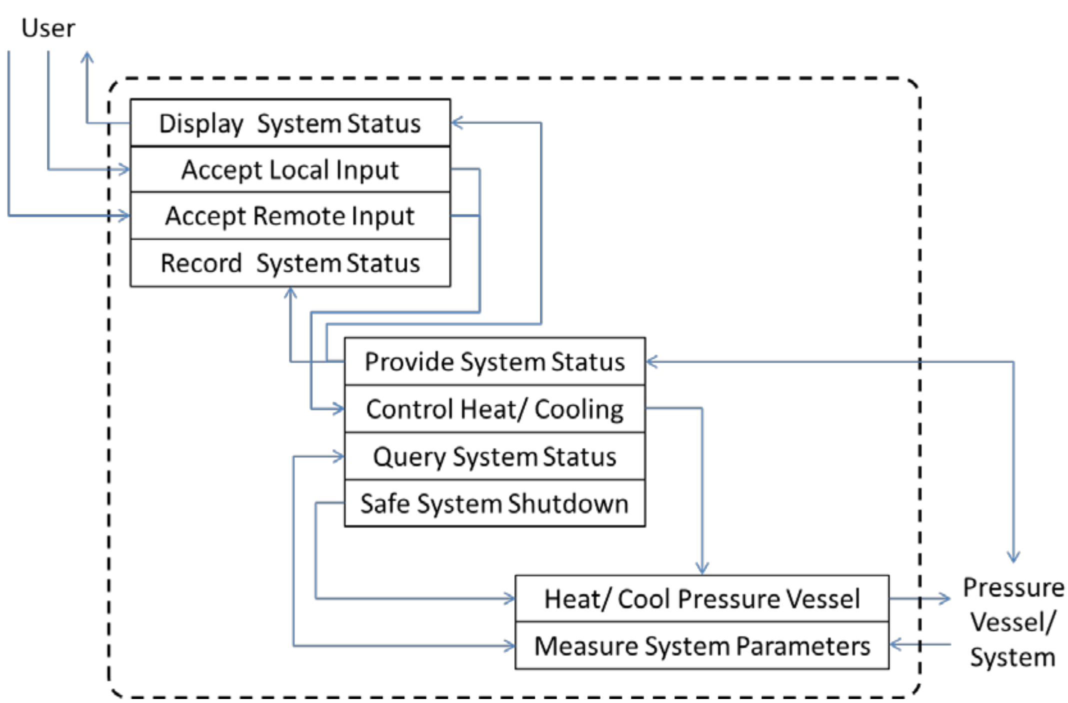

Figure 13: Functional architecture of proposed Thermal Control System

8 System Requirements

The TCS system requirement are derived by synthesizing the expectations of the all the stakeholders with particular emphasis on the sacred expectation of the active stakeholders. The developed requirements are shown in Table 5.

	Requirement	Expectation
Temperature	The maximum processing set-point temperature at which the glycerin in the pressing vessel shall be required to be maintained is 135 C (275 F).	Operate reliably
	The minimum processing set-point temperature at which the glycerin in the pressing vessel shall be required to be maintained is 40 C (104 F).	Operate reliably
	The temperature of the glycerin within the pressing vessel shall be uniform throughout the liquid volume and not vary by more than +/- 2.8 (5 F)	Operate reliably
	The temperature of the pressing vessel shall not exceed 149 C (300 F).	Be safe to operate
	Glycerin set-point temperatures between 40 C (104 F) and 135 C (275 F) shall be achieved within 24 hours from a starting ambient condition of 20 C (68 F).	Operate reliably
	The ability to ramp up to and down between to two glycerin set-point temperatures over a 24 hour period shall be provided.	Operate reliably
Physical Environment	The heating and control system shall be compatible with the existing press hydraulic system and not hinder the hydraulic operation of the press.	Integrate into existing facility
	The heating system and control system shall minimize any facility modifications required within the facility and surrounding area.	Integrate into existing facility
	Local and remote control of the thermal system shall be provided.	Ease of use, Ease of maintenance
	Structural components shall be designed to comply with the seismic restraint requirements in the most recent version of the California Building Code.	Be safe to operate
	The thermal system shall be designed to preclude personnel from getting harmed by touching or getting into close proximity of any heated systems or components.	Be safe to operate Ease of use
	The arrangement and choice of material in the design and fabrication of the heating system shall be in accordance with the DOE Explosive Safety standard DOE-STD-1212.	Be safe to operate
Electrical	All components shall be rated to NEC defined Class II (powders/ dust) Division 1 (normal conditions) hazardous location.	Be safe to operate
	The use of electrical components shall be in accordance with the DOE Explosives Safety standard DOE-STD-1212.	Be safe to operate

	A 480VAC, 3 phase power connection shall be provided.	Operate reliably
	If the thermal control system is electrically based a manual reset secondary over temperature system which interrupts the heating supply power shall be provided in the event the primary over temperature limiting system fails.	Be safe to operate
Control	The set temperature shall be maintained within +/- 3 C across the temperature range of 40 to 120 C.	Operate reliably
	The ability to program a time and temperature profile shall be provided. A given profile may extend up to 96 hours.	Ease of use
	The ability for temperature profile programs to be saved and be available for later recall and use shall be provided.	Ease of use
	The ability to remotely start or stop the TCS for the press, within a 96 hr. future time period window, shall be provided.	Ease of use
	An independent high temperature shut-off system shall be provided such that the press heating system does not exceed the maximum set-point temperature.	Be safe to operate
	The ability to record press temperature data shall be provided.	Ease of use
	Two control locations shall be provided, one local in the immediate vicinity of the press and other in the control room located in R118 approximately 30 ft. away.	Ease of use
	Controls shall take into account Human Machine Interface factors	Ease of use, Operation reliably
	All components and operational capabilities of the control system shall be in accordance with the DOE Explosives Safety standard DOE-STD-1212.	Be safe to operate
	The press control shall have the ability to provide a remote alarm signal, alerting that the press has exceeded its set point temperature.	Be safe to operate

Table 5: System Requirements of the Thermal Control System

In order to aid the design and development of the thermal system a Qualify Functional Diagram (QFD) was developed to identify those requirements which should be considered of particular importance, Table 6. Interesting it revealed the importance of cost (indicated as green in QFD), which were not reflected as a sacred expectation of active stakeholders, but is clearly a requirement imposed by the budgeting organization. As expected safety ranked high (yellow) with ease of use and maintenance reflected as well (orange). And finally the integration of the thermal system scored high as well (blue).

	Capability												
Characteristic	Cost	Control of Temperature	Uniformity of Temperature	Footprint	Power Consumption	MTBF	Safe Failure Mode	Local and Remote Control	Display and Record Temperature	Set Start Time	Provide Remote Status	Meet Explosive Safety Standard	Meet LLNL ESH Requirement
Operate reliably	9	9	9	1	0	9	1	3	3	3	3	3	3
Ease of use	3	3	3	3	0	3	1	9	9	9	9	3	3
Ease of maintenance	3	3	1	9	1	9	0	9	1	0	3	1	1
Be safe to operate	9	9	9	1	1	1	9	3	3	1	1	9	9
Integrate into existing facility	3	1	0	9	9	0	1	3	3	1	0	9	9
Scoring	27	25	22	23	11	22	12	27	19	14	16	25	25

Table 6: QFD for the Thermal Control System

9 Organizational and Business Impact

The successful development and implementation of the TCS is foundational to the overall success and operational capability of the HE Pressing Complex. As it has sat dormant for number of years, the need for it has become increasingly important. Especially with the continue problem plaguing the existing pressing capabilities. Multiple program elements at LLNL have expressed interest in having this capability operational.

No significant changes are expected to existing processes developed for the functioning (albeit unreliably) press facility. Shown is a process diagram (Figure 14) for this operation. The operations at non-operational facility will essentially be the same.

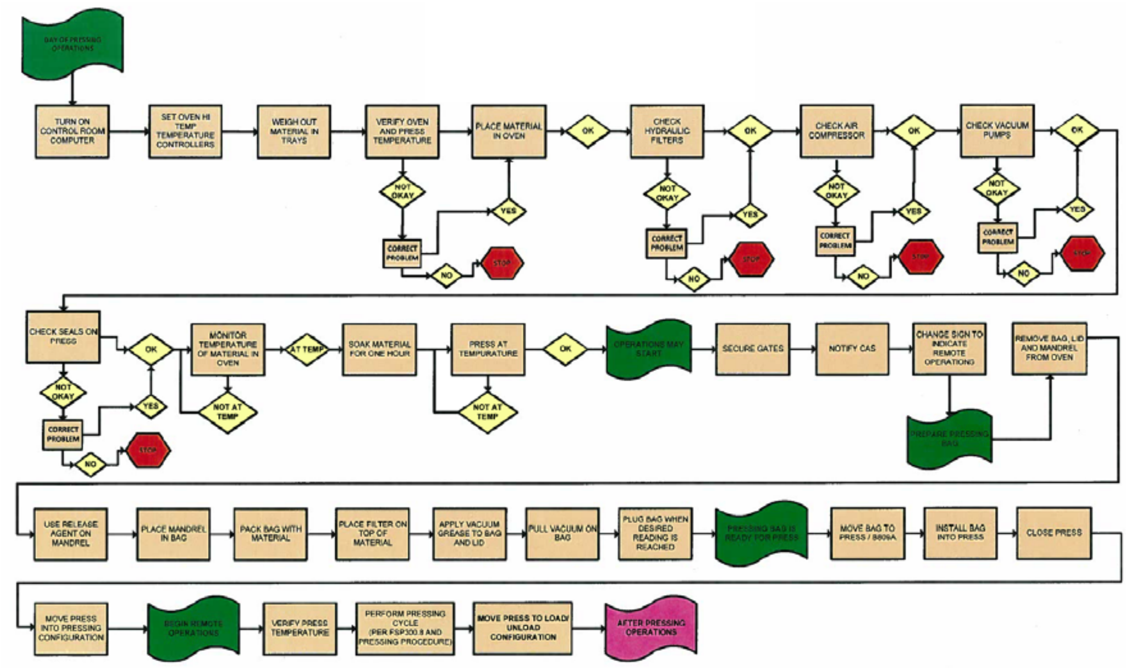

Figure 14: Existing pressing operations

There will be a significant effort to complete the implementation or execution of the project which will address the design, procurement, fabrication, assembly, installation and acceptance of thermal control system in the facility. Training and maintenance plans will be developed to ensure operators and maintenance technicians are qualified to operate and maintain the system.

During the design phase of the project, design reviews will be held to ensure selected design meet system requirements. Additional work in the area of Failure Modes and Effect Analysis as well as an analysis of expected failure rate will be completed. The performance of work at the pressing facility in support of the installation and acceptance will follow existing work control protocols to ensure all activities are properly bound, hazards identified and mitigated. The management of the above steps and processes as well others required for successful project execution will be managed by an infrastructure recapitalization program staff currently executing similar project at LLNL.

10 Risks and Technology Readiness Assessment

Any new undertaking carries with it some level of risk; this of course is true for the development of the proposed TCS. The following general risks have been identified, as the design becomes more developed these general risk categories will be carried into the more defined subsystem.

- Ability of TCS system to integrate into existing/ legacy press system.

- TCS utility requirements (power, water, etc.) are capable of being met without extensive modification.
- Will TCS meet system requirements and stakeholder expectations?
- Can TCS be design, built and installed within cost and schedule estimate?
- Will vendors be able to build/ provide parts and components that meet HE and AHJ safety requirements
- Will funding be available to implement execution plan.

With regard to technical assessment and readiness, there are no identified technical risk items as all components are commercially available items and technology. The one area of technology risk would be in the area of the quality of computer control software that needs to be developed. This specific item is considered part of the general risk of not meeting expectations and requirements.

In addition a risk matrix has been developed to determine the level of risk. The matrix consists of evaluating the consequence of risk against the probability of the risk occurring. These are subjectively determined but do assign a level of importance to the risk and can be used to determine how the risk should be dealt with; whether to mitigate, transfer, avoid or accept.

The development of the risk level is shown in Table 7, and is simply the product of the probability and consequence values. Risk levels in the upper right quadrant are considered high and not acceptable; they should be avoided or transferred. The middle risk levels should at minimum develop mitigation strategies to reduce the risk. The lower left quadrant maybe considered to be acceptable or minor with simple mitigation employed.

			Risk Level		
Consequence	High	3	3	6	9
	Med	2	2	4	6
	Lo	1	1	2	3
			1	2	3
			Low	Med	High
			Probability		

Table 7: Risk matrix

The risk matrix was employed to assess the identified risk as well as start the development of an approach to address the risk, as shown in Table 8.

Risk	Consequence	Probability	Risk Level	Approach to Risk
Ability of TCS system to integrate into existing/ legacy press system.	3	2	6	Mitigate: collect existing documents and specification. Use interface control documents between TCS and legacy systems
TCS utility requirements (power, water, etc.) are capable of being met without extensive modification.	3	2	6	Mitigate: collect existing documents and specification. Use interface control documents between TCS and legacy systems
Will TCS meet system requirements and stakeholder expectations?	3	2	6	Mitigate: Provide thorough design reviews with appropriate stakeholder participating and signing off on proposed design. Quality assurance of software and acceptance testing of subsystems will be required.
Can TCS be design, built and installed within cost and schedule estimates?	2	3	6	Mitigate: develop a cost loaded schedule for all major activities with significant milestone to track progress of project. Internally track progress weekly and report out month to management.
Will vendors be able to build/ provide parts and components that meet HE and AHJ safety requirements?	3	1	3	Avoid: specify in procurement documents requirements and specification to be meet.
Will funding be available to implement execution plan?	3	1	3	Accept: carry out project until the time this becomes known. Then implement de-scoping, deferring and cost reduction activities.

Table 8: Risk levels for identified risk

There are a number of open issues that will be required to be sorted out and understood as this project progresses. The primary one being the specifics of how and in what form the integration of the TCS should take with regard to the hydraulic pressure system of the press. This issue lends itself to the consideration of applying a system engineering approach to the overall pressing capability provided in the pressing complex. Additional process steps associated with receipt of HE material, preheating of the HE powder prior to the bagging operation and the bagging process itself lend themselves to a systems engineering approach to address technical requirements as well as operational expectation of the stakeholders and users.

11 Acronym List

ASME	American Society of Mechanical Engineers
CI	Control Interface
DOE	Department of Energy
ES&H	Environmental, Safety and Health
HCU	Heating/ Cooling Unit
HE	High Explosive
LLNL	Lawrence Livermore National Laboratory
NEC	National Electrical Code
NFPA	National Fire Protection Associated
NNSA	National Nuclear Security Agency
OSHA	Occupational Safety and Health Administration
PS	Pressure System
PV	Pressure Vessel
SSMP	Stockpile Stewardship Management Plan
TC	Temperature Controller
TCS	Thermal Control System
WCI	Weapons and Complex Integration

12 Disclaimer

The paper was created in response to a requirement for a System Engineering course taught on-site at LLNL. Any reference herein to a specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. government or the Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. government or the Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.